



RCA INSTITUTES

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Technical Lesson 24

CHARACTERISTIC CURVES

The characteristic curves of a vacuum tube show the relation between the plate current and the filament voltage and plate current and the applied grid voltages. The fundamentals may be explained by their use which enables the operator to adjust the tube for certain required functioning.

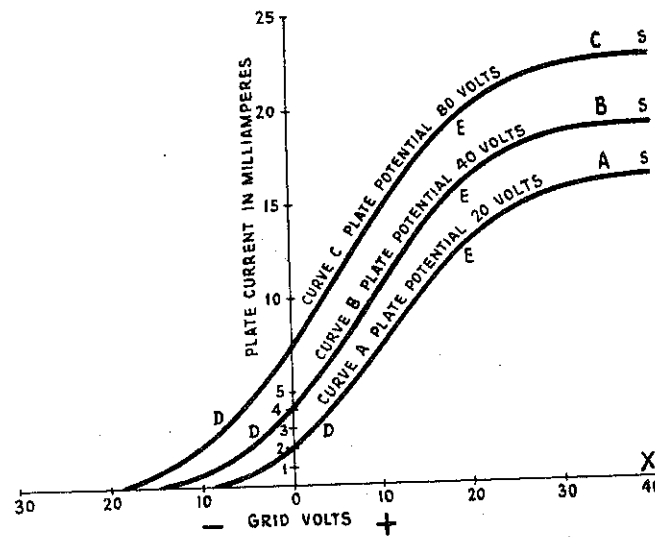


Figure 1

Figure 1 shows three curves, A, B, and C. Curve A represents the changing plate current for each change in voltage applied to the grid of the tube when the plate voltage is maintained constant at twenty volts and the filament current is kept at a constant value. Follow curve A to the left; at its lower point you will find that the plate current reaches zero. This happens because the grid is given a negative potential as shown by the grid voltage which is marked along the X axis. When the grid is strongly negative the electrons from the filament are prevented from passing to the plate and, in consequence of this fact, no plate current flow results. The grid, being negative, stops the electron flow to the plate. When, however, the potential applied to the grid becomes less negative more electrons are allowed to pass to the plate. When the grid becomes positive and is increased in positive value the plate current will correspondingly increase. This increasing value of plate current is shown by the straight portion of curve A between points D and E.

If the grid voltage is continuously increased in positive value there will be a point reached where the plate current will cease to increase. This is termed the point of saturation. By the term, "point of saturation", we mean that, provided the filament voltage and plate voltage are kept at a constant value, any further increase in positive potential value on the grid will not increase the plate current flow. This is indicated by the flattening of the curve at point S and is called the point of saturation. When the positive potential of the grid is further increased the current flowing in the circuit may start to decrease. This is caused by the fact that the grid has become so highly positive that it robs the plate of electrons which otherwise would have passed to the plate.

GRID CURRENT

When the grid is made positive it is obvious from the law, "unlike charges attract", that the grid will attract the electrons to itself from the filament just as a positively charged plate will attract electrons. Since a movement or flow of electrons constitutes a flow of current it is evident that, with the grid positive, there will be a flow of electrons or current in the grid and through any circuit connected to the grid.

A large grid current flow is not desirable in the radio circuit and means are taken to keep it down to a minimum value which will be explained later. The only function intended of the grid is to control the current flow in the plate circuit. When current flows in the grid it must be subtracted from the current that would normally flow in the plate circuit since both the grid and plate current originate from the electrons emitted by the filament. It is seen, then, that a positive grid tends to rob the plate of electrons and sets up a current in the grid circuit performing no useful work and reduces the plate current flow. A small grid current is put to useful purpose, as explained in detector action. Grid current is practically prevented by maintaining the grid negative through the use of what is termed a grid biasing battery, commonly called the "C" battery, and placing it in the grid circuit with its negative pole connected to the grid.

Curves "B" and "C" of Figure 1 differ only from curve "A" in that curve "B" indicates 40 volts used on the plate while in curve "C" eighty volts was applied.

In all three curves the same filament voltage was maintained, the general form of all the curves being practically the same.

THE VACUUM TUBE AMPLIFIER

Before taking up the action of the vacuum tube employed as a detector we will consider it as an amplifier for the reason that its fundamental actions are more easily understood. We will, for this purpose, use a vacuum tube circuit with supplementary curves to describe the action as we proceed.

Figure 2 represents a circuit which we will use to describe the principle of the tube as an amplifier. It was explained that when a positive voltage is placed on the grid the resulting flow of plate current will also assume a certain increased value. When, however, the grid voltage is changed the plate current will also make a corresponding change, the exact amount depending upon the characteristics of the tube. The tube acting as an amplifier should operate on the straight portion of the characteristic curve or the part of curve A, of Figure 1, between D and E.

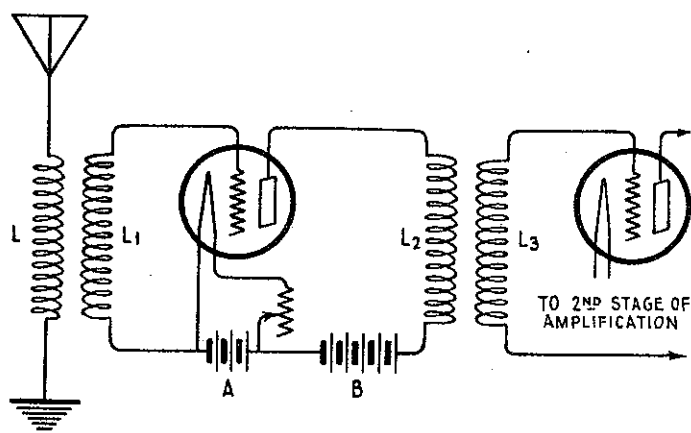


Figure 2

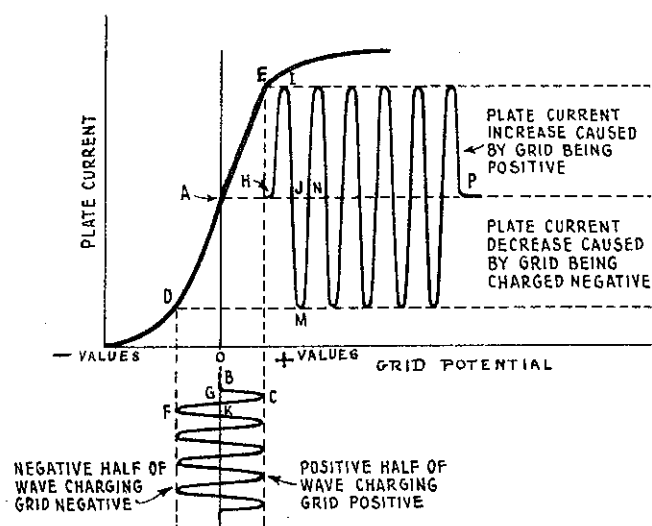


Figure 3

Now let us return to Figure 2. When an incoming Radio wave is impressed on coil L1 through induction by coil L the wave will alternate and the oscillations composing this wave will be regular oscillations, that is, each oscillation will alternately vary from a positive to a negative value. When the wave is made up of continuous oscillations the positive value may be considered practically equal to the negative value. In the damped wave, however, each half oscillation will be somewhat less than the preceeding half oscillation. We will consider the wave to be a continuous one. When it is impressed upon coil L1 it will introduce in the grid circuit of the tube an alternating current. This will cause the grid to become positive one instant and negative the following instant. When positive, an increased plate current flows and, when negative, the plate current will decrease. This action is shown by the curve Figure 3.

By carefully studying this curve it will be seen that, because the grid voltage varies equally, the increases of current in the plate circuit are followed by decreases of equal magnitude.

In Figure 3 the zero voltage line is shown intersecting the characteristic curve at its mid-point A. When an alternating current B C G F K, and so on to Z, which is representing the incoming wave, is impressed on the grid, the tube will operate over that portion

of the characteristic curve between the points D and E. This, you will observe, is on the straight portion of the curve, and the distance DA will be equal to AE.

B C G, which is the positive half of the incoming signal wave will therefore produce a plate current variation shown by the letters H I J, while the negative half of the signal wave G F K will produce a plate current variation J M N which will be equal but opposite to H I J. These variations of plate current produce a plate current of a pulsating nature as shown between points H and P, the form of which will be exactly similar to the form of the incoming signal wave, B C G F K. The amplitude, however, will be different in that the variations of plate current will have a much greater amplitude than that of the incoming signal which was impressed on the grid.

The fundamental idea of amplification is that, for a given variation in grid voltage, there will be a greater, or amplified variation in the plate current. The plate variations, although greater in amplitude than the grid variations, will be exactly similar in form.

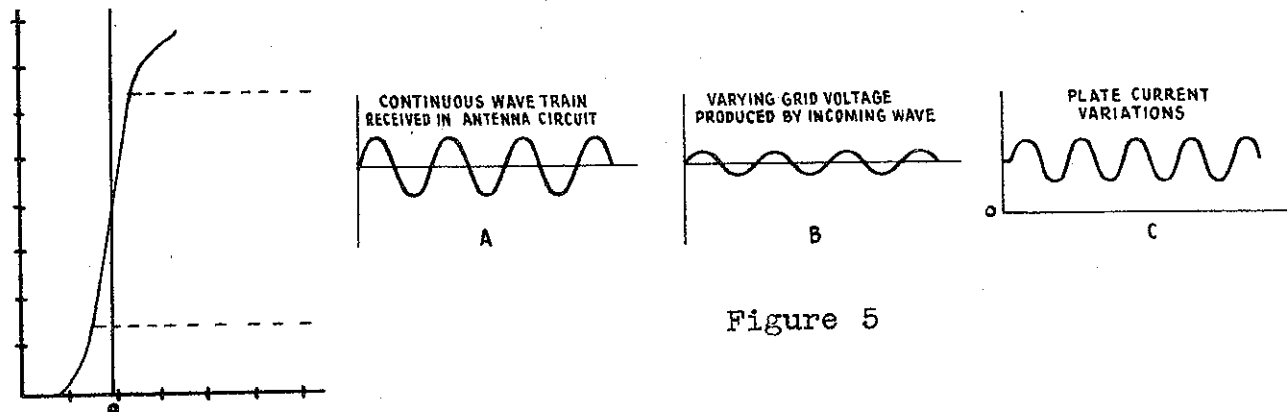


Figure 5

Figure 4

For a given grid voltage the plate current has a given strength while operating on the straight portion of the curve. If the characteristic of the tube, however, is such that the curve will have a steep slope at the operating point, as shown by the curve of Figure 4, then the variation of the plate current would be quite large for a given variation of the grid voltage.

The magnitude of amplification will depend in part upon the characteristics of the particular tube to be used and also upon the voltage charge applied to the grid. The applied grid voltage can be controlled by the operator of the receiver but the amplifying factors of the tube, that is, the amplification constant is entirely dependent upon the design of the tube itself.

In reference to the varying plate current it is desirable to make clear at this time that, although the plate current varies constantly and regularly, it cannot be called an alternating current because it

does not have negative values. It has only successively large and small positive values.

Suppose we use the tube as an amplifier with a plate potential of twenty volts. Inspection of curve A of Figure 1 will bring out the fact that, with the grid normally at zero potential, the plate current variation will not be as large as in the previous case of Figure 3 due to the smaller slope of the curve at point D. It must be remembered that, for best results in amplification, we must work on the steep part of the curve.

The variations of current through the different circuits can now be shown by the graphs A, B, and C in Figure 5.

Graph A represents a continuous wave train being received in the antenna circuit. This induces a current in the grid circuit L1 of Figure 2. The varying voltage applied to the grid is shown by graph B. This varying grid voltage will cause the plate current to vary as represented in graph C.

In graph C special note should be taken of the variation of the plate current for it shows the current starting at some fixed positive value and varying from greater to lesser positive values. This varying plate current, on passing through the primary winding L2 of the transformer in Figure 2, induces in the secondary L3 an alternating E.M.F. which sets up an alternating current flow in the grid circuit of the second tube.

The plate current through L2 of the first tube is greater than the grid current induced in L1 of the same tube. By using the transformer to transfer energy from L2 to L3 the voltage impressed on the second tube will then be much greater than that on the first tube. The character of the variations, however, will remain the same as those of the first tube.

THE TUBE DETECTOR

The purpose of the vacuum tube as a detector is to rectify the radio frequency currents collected by the receiving aerial.

The vacuum tube may be used in two ways to obtain rectification (detection). One of these methods is to connect the tube in the circuit, and adjust the grid, plate, and filament voltages to the extent that the normal operation will occur at the bend of the characteristic curve of the tube, and it is thus utilized to obtain detection. This is called the plate current method of rectification.

The other method in which the tube may be used as a detector is to include in the grid circuit of the detector a grid leak and grid condenser. When used in this way detection is obtained by grid current rectification.

When using the method first stated the tube rectifies because the increases and decreases of plate current are made unequal when changes in the grid voltage are applied when operating at the bend of the characteristic curve.

In Figure 6 we have a grid voltage plate current curve which is similar to the curves shown in Figure 1. This curve has been explained and it shows the change in plate current for a given change in grid voltage.

We will now assume that the grid is biased at two volts negative. The normal plate current is indicated by the horizontal line P.C. which we have arbitrarily assumed to represent .2 milliamperes. A continuous radio wave is now impinged upon the antenna, setting up therein an alternating E.M.F. which in turn causes an alternating E.M.F. to be impressed upon the grid of the tube through suitable coupling devices. This incoming signal wave is clearly shown in Figure 6 along the grid voltage line.

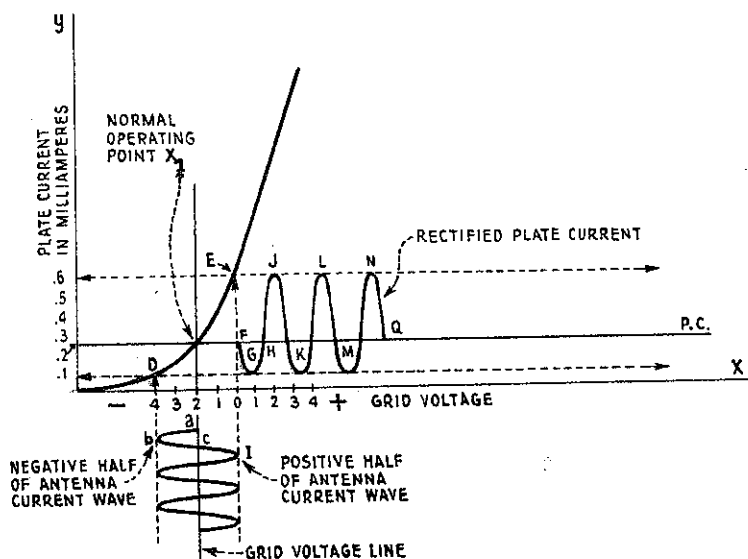


Figure 6

The incoming signal wave will have a certain voltage which is alternating first positive and then negative and it will add to or subtract from the voltage already on the grid. When no signal wave is being received the grid voltage is normally 2 volts negative shown by the grid voltage line which intersects the characteristic curve at "X₁". At this point of intersection a horizontal line, P.C., is drawn parallel to the "X" axis indicating the normal plate current flow with the grid at 2 volts negative. The incoming signal wave is now impressed upon the grid and, as shown, is of equal amplitude on both sides of the grid voltage line. The maximum amplitude of this wave is shown to the left of the grid voltage line of negative two volts and it will decrease the negative charge already on the grid to 4 volts negative. Following the dotted line from the maximum point of the amplitude it will intersect the curve at "D", and the horizontal dotted line drawn parallel to the X axis shows the value of the plate current flowing when the grid is at 4 volts negative potential. The grid voltage was made more negative, as just stated, by the negative voltage of the incoming wave being added to the negative charge already on the grid.

The negative amplitude of the wave now begins to decrease and, on reaching the grid voltage line, the grid will be restored to its normal condition, having a charge of 2 volts negative. This will cause the plate current to increase as represented by the curve between points D to the normal operating point of the curve "X₁". The wave now increases in amplitude from C to I; this half of the wave, being positive, it offsets the 2 volts negative charge reducing it to zero with a resulting plate current increase represented by "E" on the characteristic curve. The form of the plate current curve will follow exactly the form of the incoming signal waves, which is shown by F G H J K etc. The plate current impulses, as shown by letters J L N, increase to a greater value above the normal plate current line PC than they decrease in value below this line, as shown by G K M, even though the amplitude or voltage changes of the incoming signal wave is equal on either side of the grid voltage line. Because the changes of the grid voltage produce this result, this method of rectification is given the name "plate current rectification". Rectification results when the operating point of the curve occurs near the lower bend or knee of the characteristic curve.

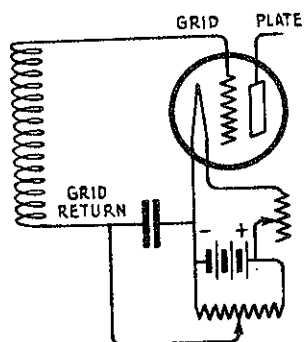


Figure 7

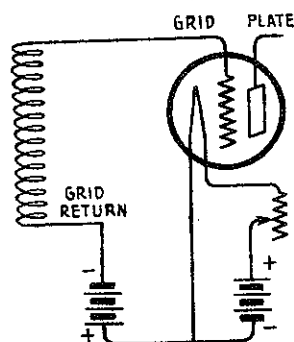


Figure 8

If the grid voltage line was made to intersect the characteristic curve higher up where the curve is nearly a straight line the increases and decreases of plate current above and below the normal plate current line would be nearly equal and amplification instead of rectification would be obtained.

BIASING METHODS

Biasing the grid may be accomplished by employing a potentiometer connected across the filament lighting battery as shown in Figure 7. The center, or movable arm of the potentiometer, is connected to the grid return and the ends of the potentiometer winding is connected to the positive and negative sides of the filament.

When the potentiometer arm is moved to the right it will place a positive bias on the grid and moving it to the left makes the grid negative. With this system a close adjustment can be secured which affords an opportunity for the operator to shift the operating point at will until the best point of detection is found.

Another method of placing a bias on the grid is to use a biasing battery, called the "C" battery. The detector circuit in Figure 8 shows how the "C" battery is connected to bias the grid. This method does not allow as fine an adjustment as the potentiometer because the operator can only vary the grid voltage by the number of taps brought out on the "C" battery and, in general, the taps are in one and one half volt steps.

Although the biasing methods just described may be used, they have been replaced in practically all radio broadcast receivers by connecting the grid return directly to either the positive or negative side of the filament, depending upon the type of tube used, that is, whether a highly evacuated or hard tube, or a gas filled or soft tube.

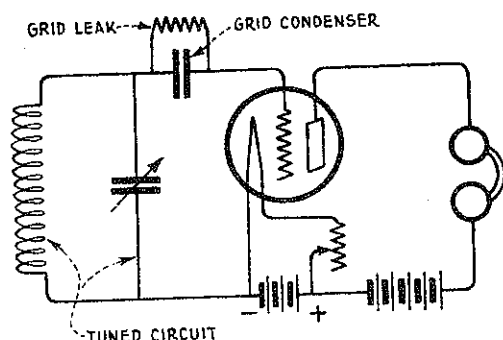


Figure 9

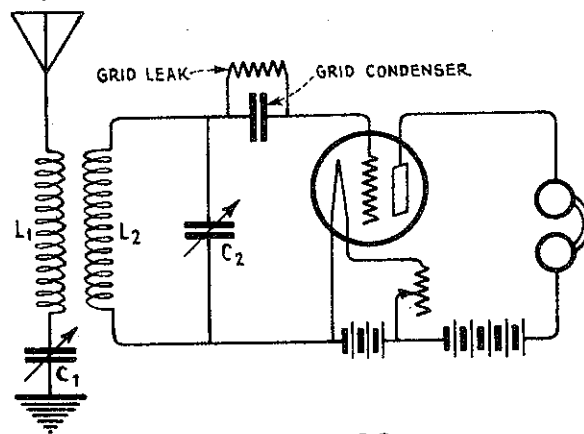


Figure 10

It is desirable when a hard tube is used as a detector to connect the grid return directly to the positive side of the filament. When using a soft tube such as the old UV-200 as a detector or the new UX-200-A, it is then considered best to connect the grid return directly to the negative side of the filament. The grid is maintained positive when connected to the positive side of the filament circuit and negative when connected to the negative side of the filament.

GRID CURRENT RECTIFICATION

When a grid condenser and grid leak are connected in the circuit of a vacuum tube detector, as shown in Figures 9 and 10, grid current rectification takes place. The only change in this circuit from the detector circuit utilizing the plate current rectification method is the omission of the grid, or "C" battery, and the insertion of a grid condenser in the grid lead. When no signal wave is being received the plate potential supplied by the "B" battery will be of a constant value with a steady current flow in the plate circuit. Practically no current will flow in the grid circuit because the grid is insulated from the filament by the small grid condenser.

Now assuming that the condenser insulates the circuit perfectly then, with this condition, the potential of the grid (only when first set in operation) will be that corresponding to a zero current in the grid circuit.

We will now assume that the antenna is energized by a damped wave. The wave will be picked up by the antenna and will pass through the inductance coil L_1 and condenser C_1 to ground and induce an E.M.F. in L_2 C_2 circuit as shown in Figure 10. Current will now flow through the grid condenser to the grid placing thereon an alternating positive and negative charge.

Refer to Figure 11A showing simply that part of Figure 10 which includes condenser C_2 , the grid condenser, and the tube elements. During the positive half cycle of the incoming oscillations, shown in Figure 11B, the grid becomes positive and the conductivity of the tube is increased, that is, electrons are assisted to the plate by the positive grid and more current flows in the plate circuit. The grid naturally will retain some of these electrons. The negative half cycle of the incoming wave passes through the same circuits making the grid negative this time as shown in Figure 12. Since the grid is negative it repels a great many of the electrons emitted by the filament and the tube becomes less conductive, and current flow in the plate circuit is reduced.

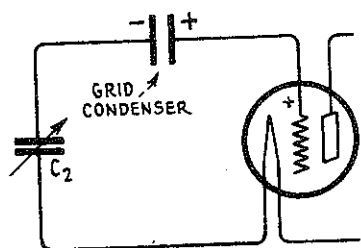


Figure 11A

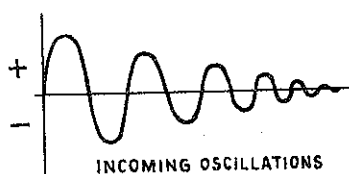


Figure 11B

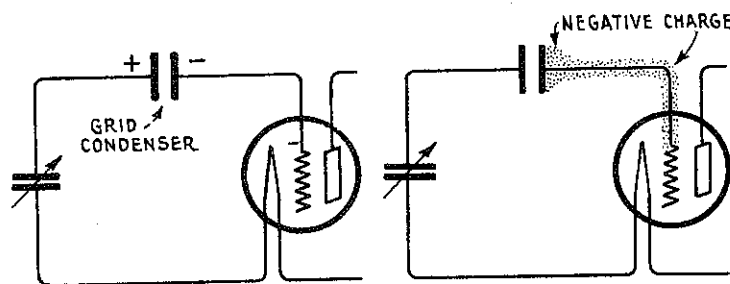


Figure 12

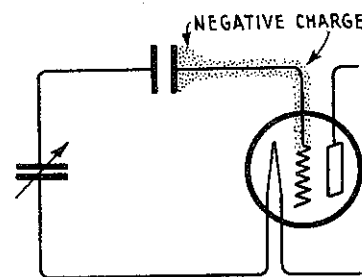


Figure 13

During the negative half cycles the grid does not lose the electrons it accumulated during the positive half cycles and, therefore, at every cycle the negative charge is built up gradually on the grid. Such a condition is suggested in Figure 13, the effect of which is to decrease the plate current flow. Each half oscillation causes the negative charges to add to the previous ones making the grid more and more negative and the plate current will therefore continue to decrease.

It is undesirable to have the grid circuit permanently retain the negative charge it has accumulated during the successive cycles of the first incoming wave train shown by curve A, Figure 14. After the damped oscillations have died out, some means must be provided for the accumulated charge to move away from the grid and thus restore the grid to its original condition of zero grid voltage before the next wave train arrives.

In the earlier types of tubes considerable gas was present in the tube due to the fact that a high evacuation of the tube could not be successfully accomplished. This gas formed a high resistance path over which the accumulated grid charge could pass to the filament, thus automatically restoring the grid to its condition of zero grid voltage before the incoming wave train was impressed upon it.

With modern vacuum pumps the tubes are more highly exhausted and it becomes necessary to provide a circuit which will allow the grid accumulation to escape. This is accomplished by placing a high resistance in parallel with the grid condenser. This high resistance is called a grid leak. Figure 10 shows how it is connected around the grid condenser.

Let us review the foregoing statements now in order to better understand the part the grid leak plays.

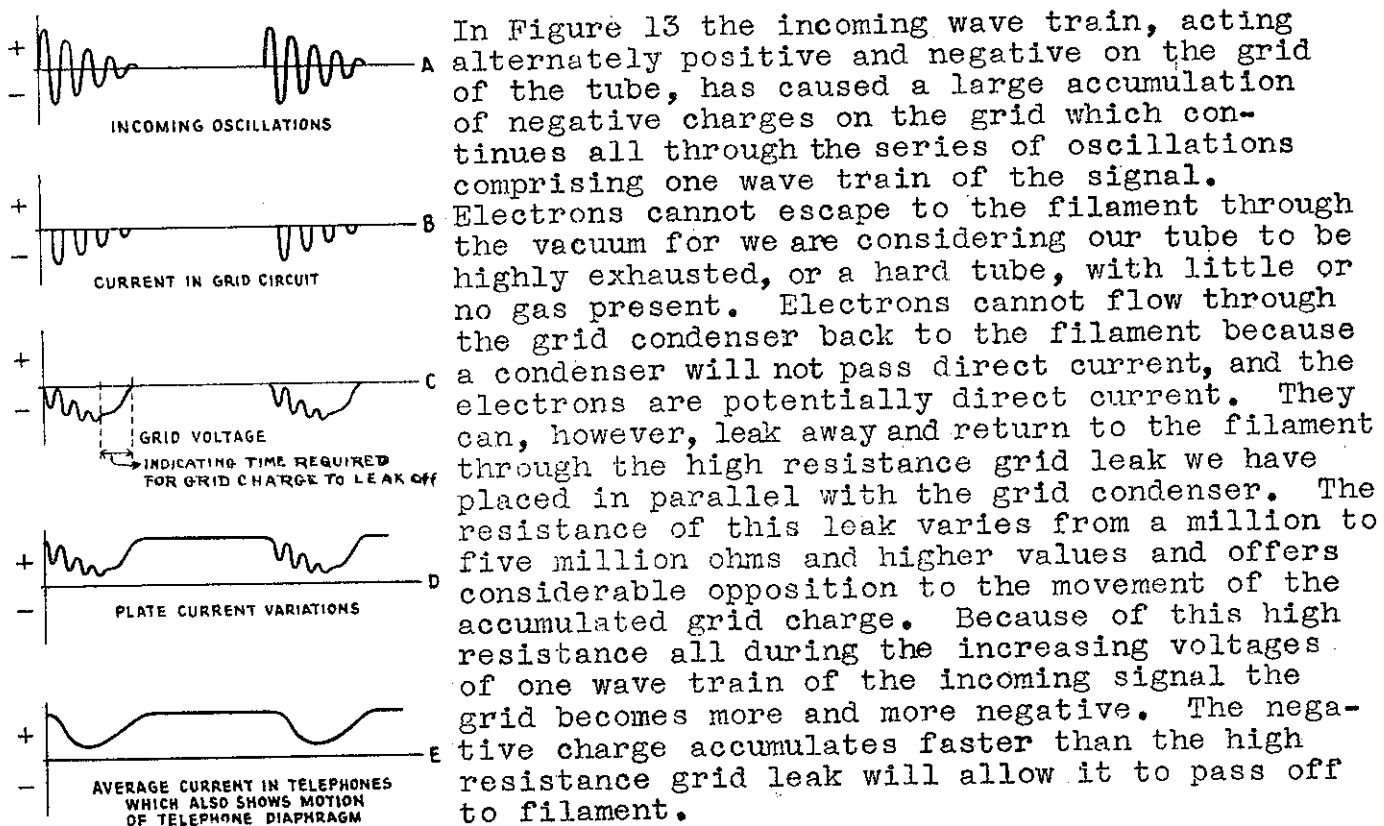


Figure 14

The value of the grid leak in ohms depends upon the size of the charge accumulating on the grid, the characteristics of the circuit, and the tube used as a detector. It should be sufficiently great to prevent the grid condenser from totally discharging before the incoming oscillations of any one group of signals have been completed, and sufficiently small to allow the completed charge to leak off between the groups of oscillations.

When the value of the leak is too small the grid condenser will not charge fully thus decreasing the efficiency of the tube and, if too large in value, it will amount to the same as no grid leak at all. For example, in a circuit having no leak and receiving a large charge the charge may jump to the filament through surface leakage across the grid condenser, or it may take place across the insulation of the tube socket. This will produce a PUTT PUTT PUTT sound in the telephones, occurring periodically as each charge accumulates and discharges. This may happen, as stated above, if the grid leak resistance is too high or if no grid leak is used.

The grid leak may be connected in either of two ways as shown in Figure 10 and Figure 15. A study of these two circuits will show that, by either connection, the results obtained will be somewhat similar, in that a path is provided for electrons to flow to the filament.

In Figure 10, the charge flows through L_2 to the filament, while in Figure 15 it flows directly to the filament without passing through inductance L_2 . This method of rectification (grid current) is a much better one to use than plate current rectification since rectification (detection) can be obtained at any point of the characteristic curve of the tube, and is the method used at the present time in practically all broadcast receiving circuits.

Figure 14 illustrates the variations in the circuits just described. Curve A, as stated is a representation of the incoming groups of oscillations. Curve B represents the grid circuit current. C indicates the grid voltage, D the plate current variations, and E the average current through the telephone receivers. Curve C is of particular interest in this series of curves because it shows the grid voltage oscillating at radio frequency, becoming more and more negative until the groups of oscillations cease and the grid charge leaks off to filament through the grid leak. The grid then assumes its normal voltage and a new group of oscillations is impressed on the circuit. Curve D shows the radio frequency oscillations in the plate circuit current. They oscillate at radio frequencies and follow the grid voltage variations, but the average plate current makes only one large variation for each group of oscillations impressed on the grid. The telephones do not respond, as you know, to radio frequencies but will respond to the average plate current variations. This average variation which affects the phones is shown at E, there being one large variation for each group of incoming oscillations.

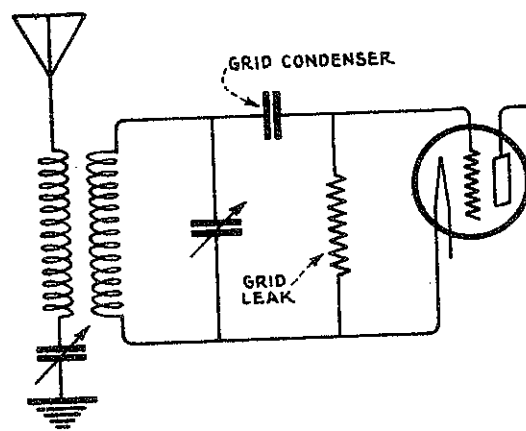


Figure 15

EXAMINATION - LESSON 24

1. What is the characteristic curve of the vacuum tube intended to show?
2. What is meant by the "saturation point"?
3. Is it desirable to have a large grid current flow?
4. How is the grid current flow prevented?
5. What is the fundamental idea of amplification in the vacuum tube?
6. What is the purpose of the vacuum tube as a detector?
7. State two ways of placing a bias on the grid of a vacuum tube.
8. What difference exists between the detector circuit employing grid current rectification and the detector circuit employing plate current rectification?
9. How is the grid condenser connected in the circuit?
10. Show by diagram two ways of placing a grid leak and condenser in the detector circuit.